INNOVATIVE **GRID-IMPACTING TECHNOLOGIES**
ENABLING A CLEAN, EFFICIENT AND SECURE
ELECTRICITY SYSTEM IN EUROPE

The European GridTech project

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Co-funded by the Intelligent Energy Europe
Programme of the European Union

Outline

- Overview of GridTech
- Technology focus and scenarios
- Pan-European study
- Data collection
- Scenario study: provisional 2020 base case results
- Next steps
- Discussion

About the project

Contract number:
IEE/11/017 / SI2.616364

Full title:
Impact Assessment of New Technologies to Foster RES-Electricity Integration into the European Transmission System

GridTech is a project co-funded by the European Commission under the **Intelligent Energy Europe** Programme.

Duration:
May 2012 - April 2015

Budget:
1,958,528

EC contribution:
1,468,896

Co-funded by the Intelligent Energy Europe Programme of the European Union

About the project

GridTech's main goal:

- Conduct a ***fully integrated assessment of new grid-impacting technologies and their implementation*** into the European electricity system.

This will allow comparing different technological options, towards the exploitation of the full potential of future **electricity production from renewable energy sources (RES-E)**, with the lowest possible total electricity system cost.

Project objectives (I)

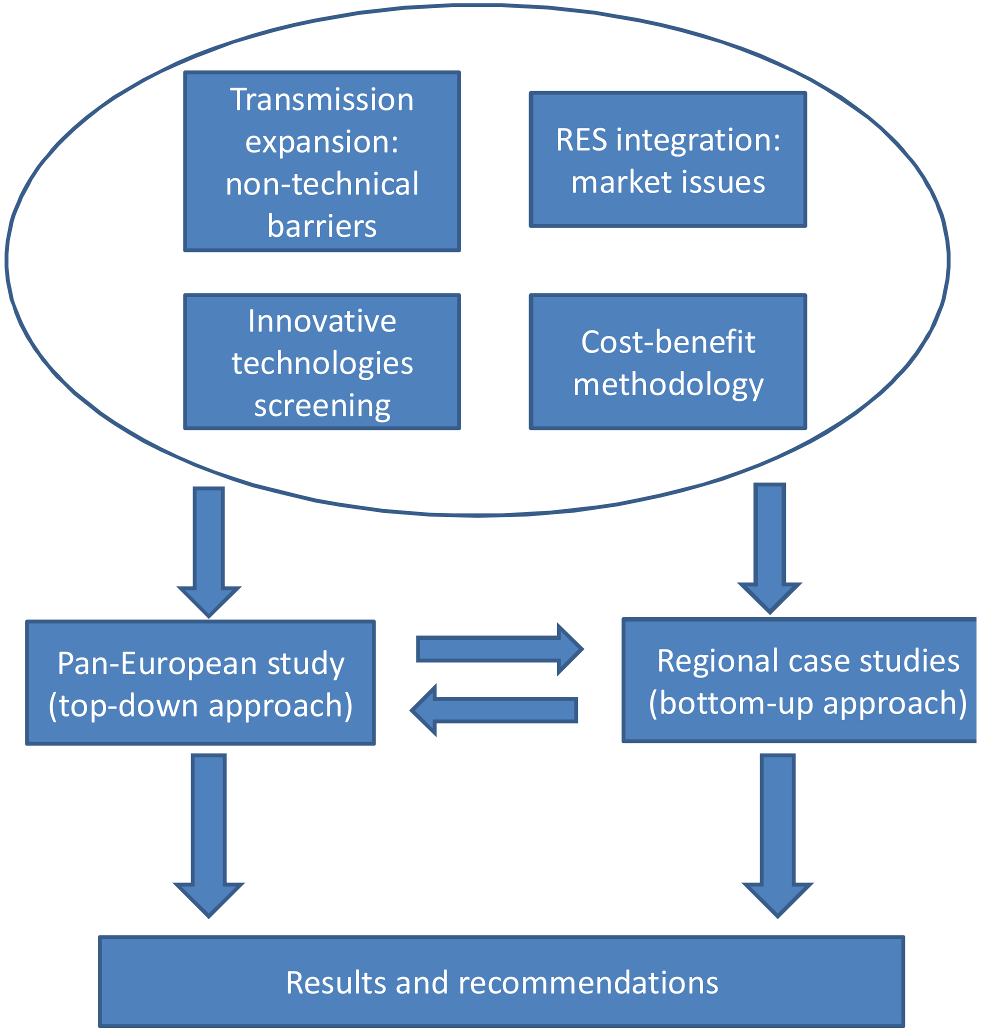
- Assess the **non-technical barriers** for transmission expansion and market compatible renewable electricity integration in Europe.
- Develop a robust **cost-benefit analysis methodology** on investments in most suitable **new technologies fostering large-scale renewable electricity integration** into the European transmission grid.
- Apply and verify the cost-benefit analysis methodology for **investments in the transmission grid, on national and European level**.

Project objectives (II)

- Achieve a common understanding among key actors and target groups on **best practise** criteria for the implementation of new technologies fostering large-scale renewable electricity and storage integration.

- Deliver tailor-made **recommendations** and **action plans**, taking into account the legal, regulatory, and market framework.

Project structure



Technology focus

The analysis focuses on the most promising and innovative technologies that directly or indirectly impact on the transmission system.

Grid-impacting technologies

- 1st category --> technologies directly impacting on the transmission system:
  → **Transmission grid technologies (TGT)**
- 2nd category --> technologies indirectly impacting on the transmission system:
  → **Electricity generation technologies (EGT)**
  → **Energy storage technologies (EST)**
  → **Electricity demand technologies (EDT)** (incl. **electric mobility technologies**)

Grid-impacting technologies: TGT

- **HVDC** (High Voltage Direct Current) OHLs/cables/back-to-back devices;
- **FACTS** (Flexible Alternating Current Transmission System) devices;
- Phase Shifting Transformers (**PSTs**);
- Wide Area Monitoring/Control/Protection Systems (**WAMS**/WACS/WAPS);
- **DLR** (Dynamic Line Rating)/**RTTR** (Real Time Thermal Rating)-controlled OHLs/cables;
- XLPE (Cross-Linked Polyethylene) underground/undersea HVAC cables;
- Fault Current Limiters (FCLs);
- High Temperature Superconducting Cables (HTSCs);
- Gas Insulated Lines (GILs);
- High Temperature (HT)/High Temperature Low Sag (HTLS) Conductor-based OHLs;
- Innovative-design HVAC OHLs;
- EHVAC (Extra HVAC) OHLs.

Grid-impacting technologies: EST

- Pumped Hydroelectric Energy Storage (**PHES**);
- Compressed Air Energy Storage (**CAES**);
- Power-to-Gas (P2G) Storage;
- Flywheel Energy Storage (FES);
- Superconducting Magnetic Energy Storage (SMES);
- Molten-salt Batteries Energy Storage;
- Flow Batteries Energy Storage;
- Supercapacitors / Ultracapacitors;
- Lithium (Li)-Ion Batteries Energy Storage;
- Hydrogen / Fuel Cell (HFC) Storage.

Grid-impacting technologies: EDT

- **Smart meters**;
- Efficient lighting;
- Smart appliances;
- Electric Vehicles (**EVs**);
- Plug-in Hybrid Electric Vehicles (**PHEVs**).

Grid-impacting technologies (overview)

- Onshore and offshore wind energy
- Large-scale solar technologies: Concentrated Solar Power (CSP) and Photovoltaics (PV)

Electricity generation technologies, with a focus on variable RES-E

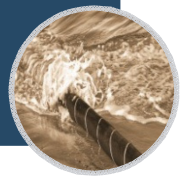
- Pumped Hydro Energy Storage
- Compressed Air Energy Storage

Bulk energy storage technologies

Demand Response Technologies/ Measures and electric vehicles

- HVDC - High Voltage Direct Current, both VSC (Voltage Source Converter)-based and CSC (Current Source Converter)-based
- FACTS - Flexible Alternating Current Transmission System
- PST - Phase Shifting Transformers
- WAMS - Wide Area Monitoring System
- DLR/RTTR - Dynamic Line Rating/Real-Time Thermal Rating-based devices

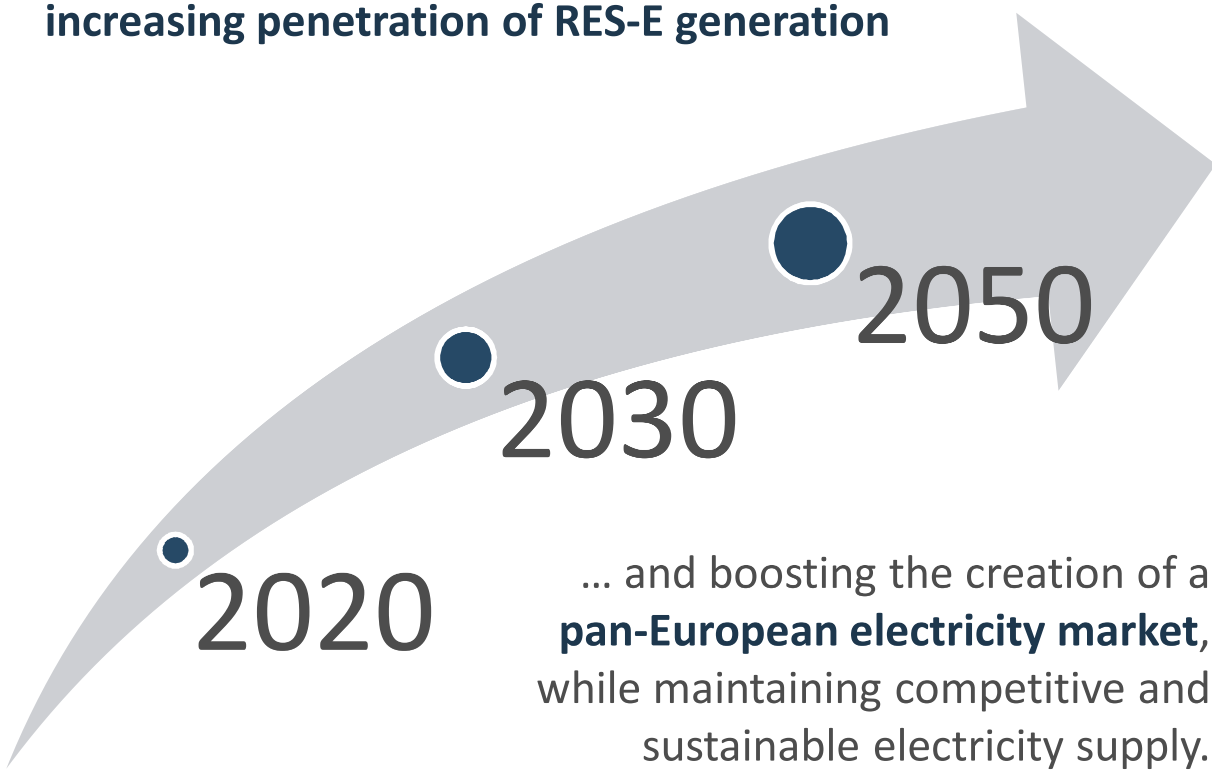
Transmission technologies directed at improvements in network control and flexible electricity system operation



2020 and beyond

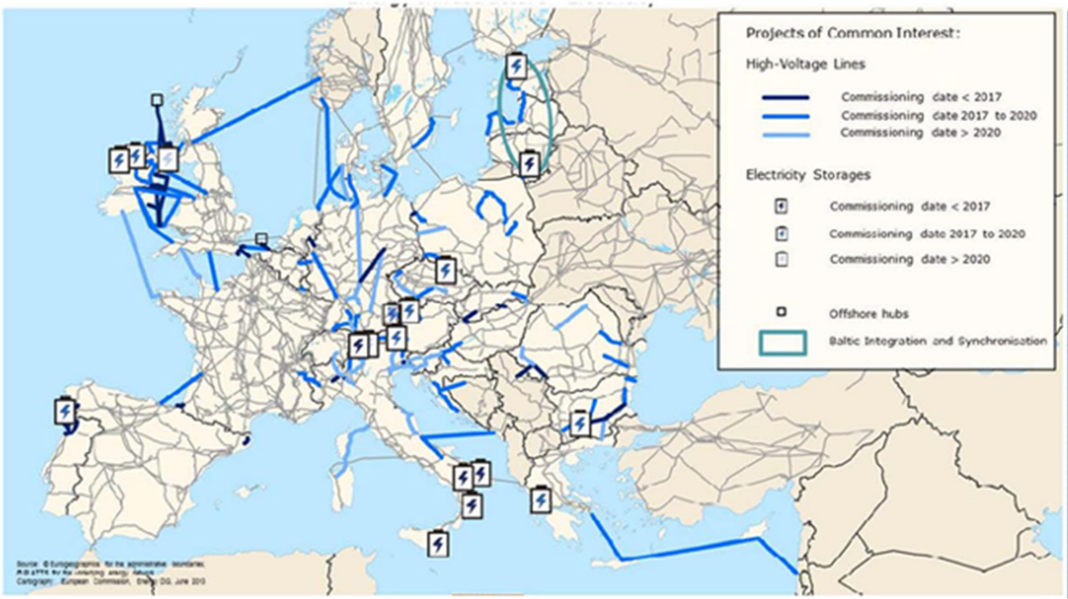
Within the 2020, 2030 and 2050 time horizons, the aim is to assess, among **innovative technologies**, i) **which**, ii) **where**, iii) **when**, and iv) **to which extent** they could effectively contribute to the further development of the European transmission grid

… fostering the **integration of an ever-increasing penetration of RES-E generation**



… and boosting the creation of a **pan-European electricity market**, while maintaining competitive and sustainable electricity supply.

Screening of TGT and EST

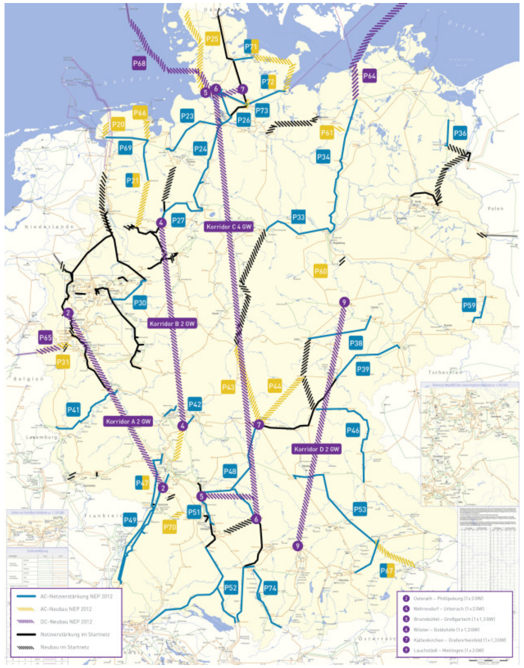


PCI projects and PECI projects

Mid/long-term grid scenarios

SuperGrid concept

A potential pan-European **SuperGrid** can be conceptually thought, upon extension of current European transmission system, as an electricity grid infrastructure based on mixed HVAC/HVDC onshore and offshore backbones (**highways**), interconnecting RES and storage technologies and transporting bulk power to load centres across the whole European continent and beyond.



Source: NEP

The SuperGrid concept includes the one of a potential overlay network as well.

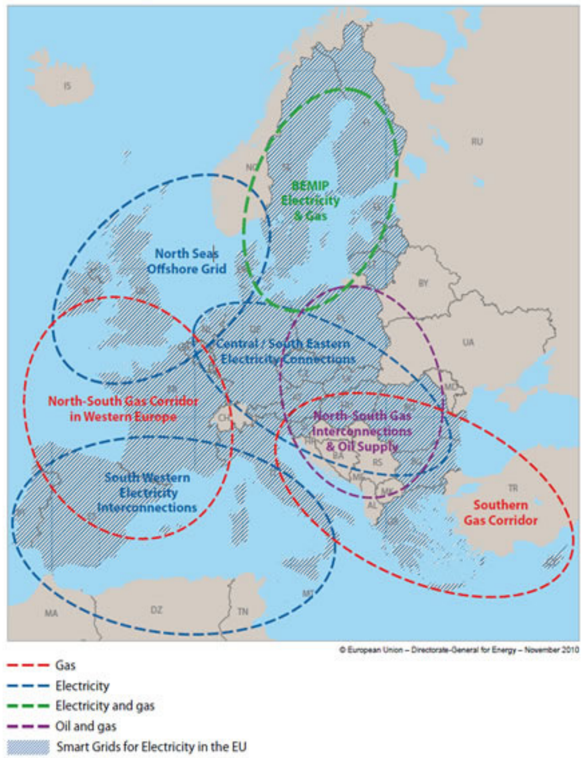
Long-term grid scenarios

Towards a potential pan-European SuperGrid?

A potential pan-European SuperGrid may include, in the long term (**2030-2050**), an enlarged HVAC continental network, synchronously interconnecting also Turkey, Baltic countries, and possibly Moldova and Ukraine, and further asynchronously interlinked with Scandinavia and British islands, embedding VSC-HVDC links and also combining offshore grids, in presence of a potentially closed (by HVAC/HVDC) MedRing and interconnections between the shores across the Mediterranean Sea.

Islands like Malta (via HVAC), Cyprus and Iceland (via HVDC) would be electrically linked to such system as well.

Russia (including Kaliningrad enclave) and Belarus would be asynchronously interconnected.

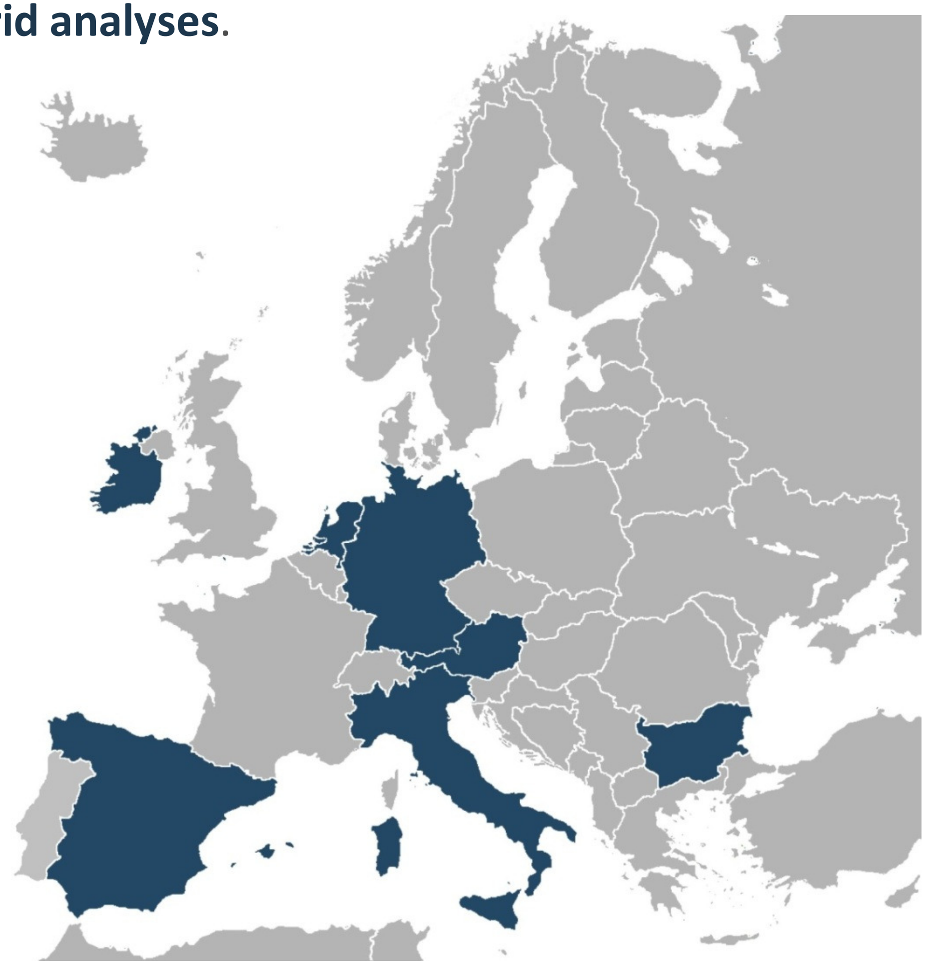


Source: EIP (2010)

Target countries

AUSTRIA
BULGARIA
GERMANY
IRELAND
ITALY
NETHERLANDS
SPAIN

In addition to top-down modelling on EU30+ and taking stock from it in a consistent data input-output flow, GridTech focuses on **7 countries**, representative of the existing and future European electricity systems, **studied at 2020, 2030 and 2050 by grid analyses**.



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Pan-European study: inputs, scenarios and preliminary results

5th Regional Energy Conference
Sofia, 28-29 October 2014

Co-funded by the Intelligent Energy Europe
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Pan-European study aims and tool

The final goal of the Pan-European study is the development and the application of a cost-benefit analysis methodology to the European system's 2020, 2030 and 2050 scenarios fostering large-scale RES-E integration.

The Pan-European study is based on a **top-down approach** by including the entire European system (EU30+) in the model: the tool for conducting this kind of scenarios analyses is MTSIM (Medium Term SIMulator), developed by RSE and already applied in EC FP7 SUSPLAN project.

Main features of MTSIM

MTSIM is a **medium-term simulator** of a generic **day-ahead zonal market** (DAM).

The model is devised to carry out **system-wide energy evaluations** (i.e. fuel consumption) and **emission evaluations** (CO_2 and other pollutants).

MTSIM **calculates a hourly clearing price all over the year**, by means of a DC Optimal Power Flow **minimizing the energy price**, considering variable fuels costs, environmental costs and hourly bid-up of each group (input of the model).

Many results are provided in output, among which:

- Hourly marginal zone prices.
- Hydro-thermal generation dispatch.
- Inter-zonal flows.
- Costs and fuel consumption.
- Revenues, CO_2 emissions, margins and market quotas.

Main features of MTSIM

A key feature of MTSIM relates to the so-called **planning modality allowing to calculate the optimal dispatch** whenever **it is possible to install <u>additional</u> interconnection capacity** between the market zones.

The calculated dispatch is **the best compromise between**:

- reduction of operative costs due to the installation of new interconnection capacity (more efficient generation dispatching thanks to bottlenecks removal), and
- additional fixed costs of the new infrastructures.

This provides an indication of the corridors that need to be reinforced.

MTSIM provides also the **possibility of including in the model innovative technologies**, such as

- HVDC
- PST/FACTS
- Storage
- DSM/DR

Scenarios definition

For building-up pan-European scenarios of GridTech, the following elements are considered.

- It has to be preliminarily clarified that at least **three scenarios** have to be considered for each target year (**2020**, **2030**, **2050**) subject of the analysis, that is S1, S2, S3. S0 is the baseline (base case) scenario at each target year.
- **S1, S2, S3**, each of them related to the target trajectories of 2020, 2030 and 2050 years, **are to be built having as main drivers two** (also interrelated) **factors: RES penetration and technology progress**. Energy efficiency improvement is taken implicitly into account within both the two drivers.
- To simplify the picture, **S1, S2, S3, at 2020 and 2030 target years, may refer to the same level of RES penetration: they are then differentiated by the TGT, EST, EDT mix at 2020, 2030, 2050 target years**. It is then assumed that not only the overall RES penetration level, but also the penetration of each specific RES technology would not depend on the deployment of technologies at 2020 and 2030 (this applies also to 2050 in a first instance).

Scenarios definition

- **S1, S2 and S3 are more ambitious than S0 in terms of technology penetration**, also in consistency with the related innovative technology review activity.
- **At 2020 all scenarios consider the achievement of RES 2020 targets: the reference case for generation/load considers the EU2020 scenario of ENTSO-E SO&AF 2013**.
- For 2020, for what concerns technology progress, **S1 includes base EDT and base EST, S2 coincides with S1 at 2020 (apart from few local sensitivities on EST), while S3 may be differentiated by including an higher level of EDT with respect to the base EDT at 2020 (depending on the countries)**.
- Apart from few local cases (eg. FACTS in Spain), **TGT shall not vary across scenarios in 2020** (to be developed in accordance with ENTSO-E TYNDP); this will however change for 2030 and 2050.
- **At 2030 the generation/load levels consider the updated V3 (RES optimistic) scenario of ENTSO-E SO&AF 2013-2014 for 2030 (with some adaptations).**
- **At 2050 the generation/load levels are to be based on 2030->2050 projections, also taking into account ENTSO-E SO&AF 2013-2014 V4, EEG study and EC Trends to 2050**.
- **The technology mixes for 2050 will include variable levels of TGT (in primis HVDC), EST and EDT for S1, S2, S3, with sensitivity analyses/subcases (also on EVs)**.

Scenarios definition

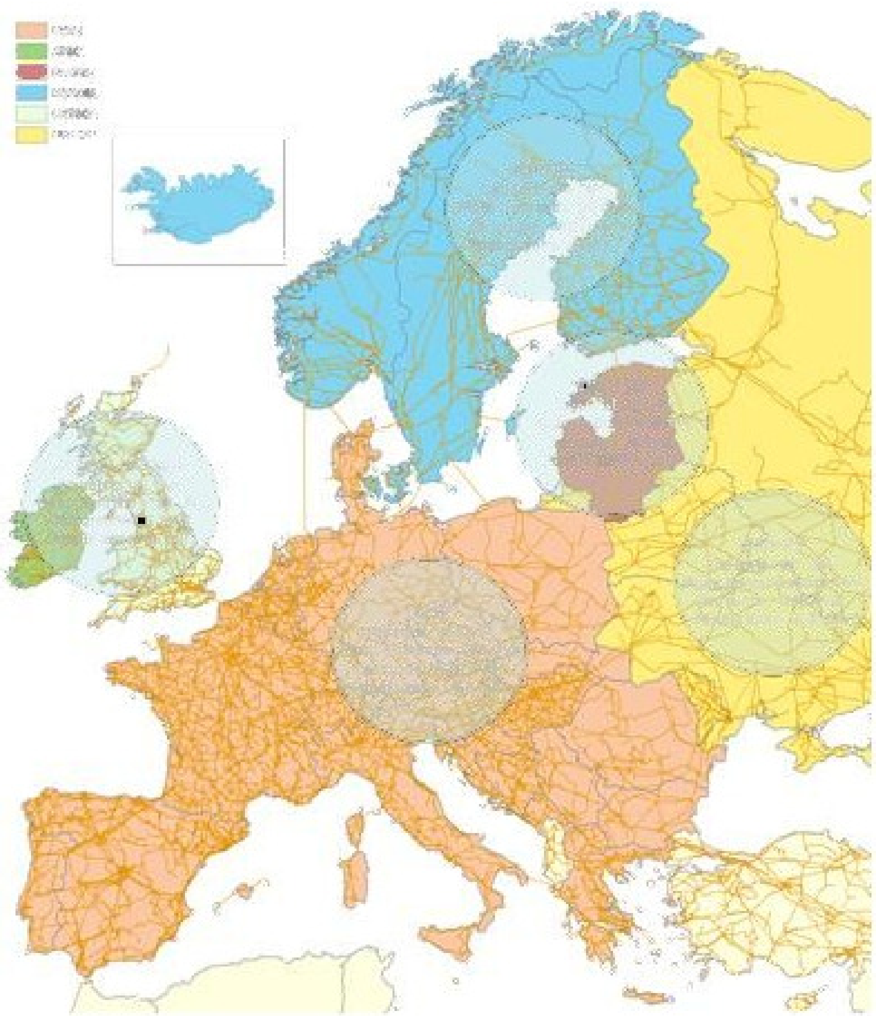
2 + 3 (+1) + 3 (+1)= 10 cases in total at most

Scenario/year	2020 (reference: ENTSO-E SO&AF2013, EU2020)	2030 (reference: ENTSO-E SO&AF2013, V3)	2050 (reference: ENTSO-E SO&AF2013, V3 2050 projection)
S0 (baseline)	TGT-2020 base EST-2020 base EDT-2020	base TGT-2030 base EST-2030 base EDT-2030	base TGT-2050 base EST-2050 base EDT-2050
S1 (TGT-oriented)	TGT-2020 base EST-2020 base EDT-2020	extra TGT-2030 * base EST-2030 base EDT-2030	extra TGT-2050 * base EST-2050 base EDT-2050
S2 (EST-oriented)	TGT-2020 base EST -2020 base EDT-2020	TGT-2030 extra EST-2030 base EDT-2030	TGT-2050 extra EST-2050 base EDT-2050
S3 (EDT-oriented)	TGT-2020 base EST-2020 extra EDT-2020	TGT-2030 base EST-2030 extra EDT-2030	TGT-2050 base EST-2050 extra EDT-2050

*: by MTSIM planning modality

Pan-European study

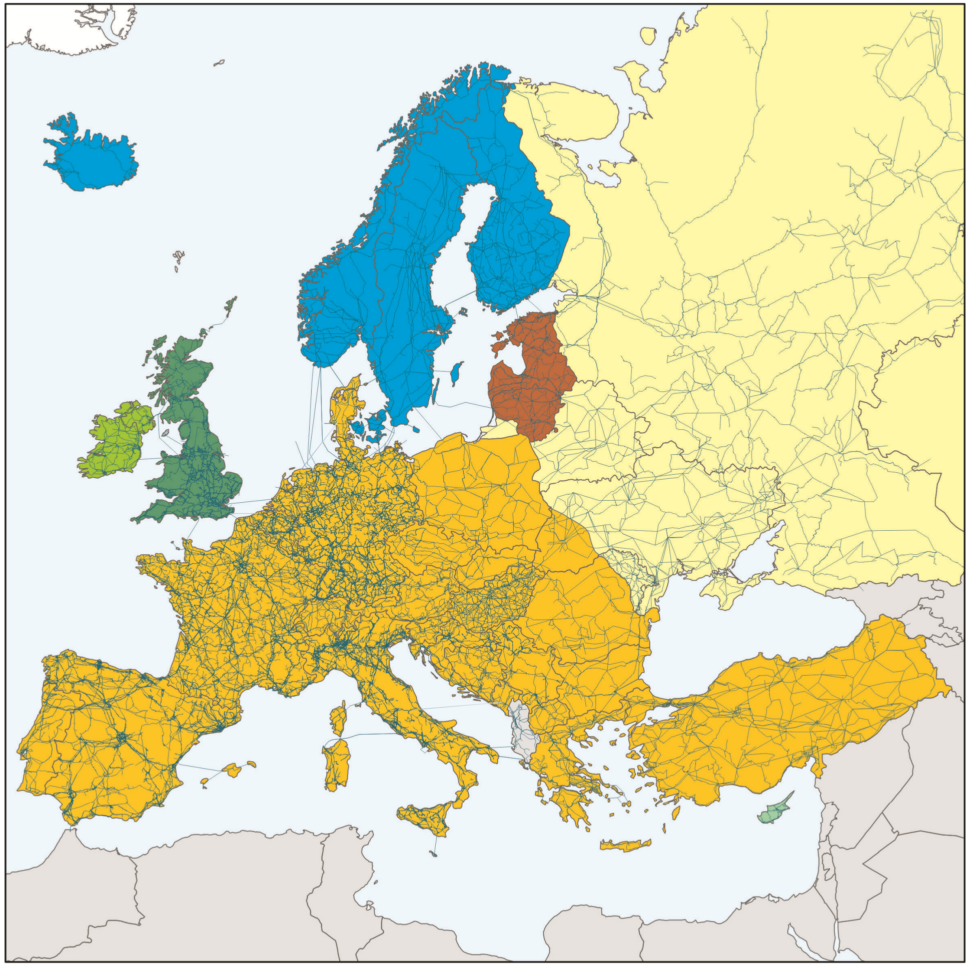
Pan-European system



Source: JRC (2010)

Pan-European study

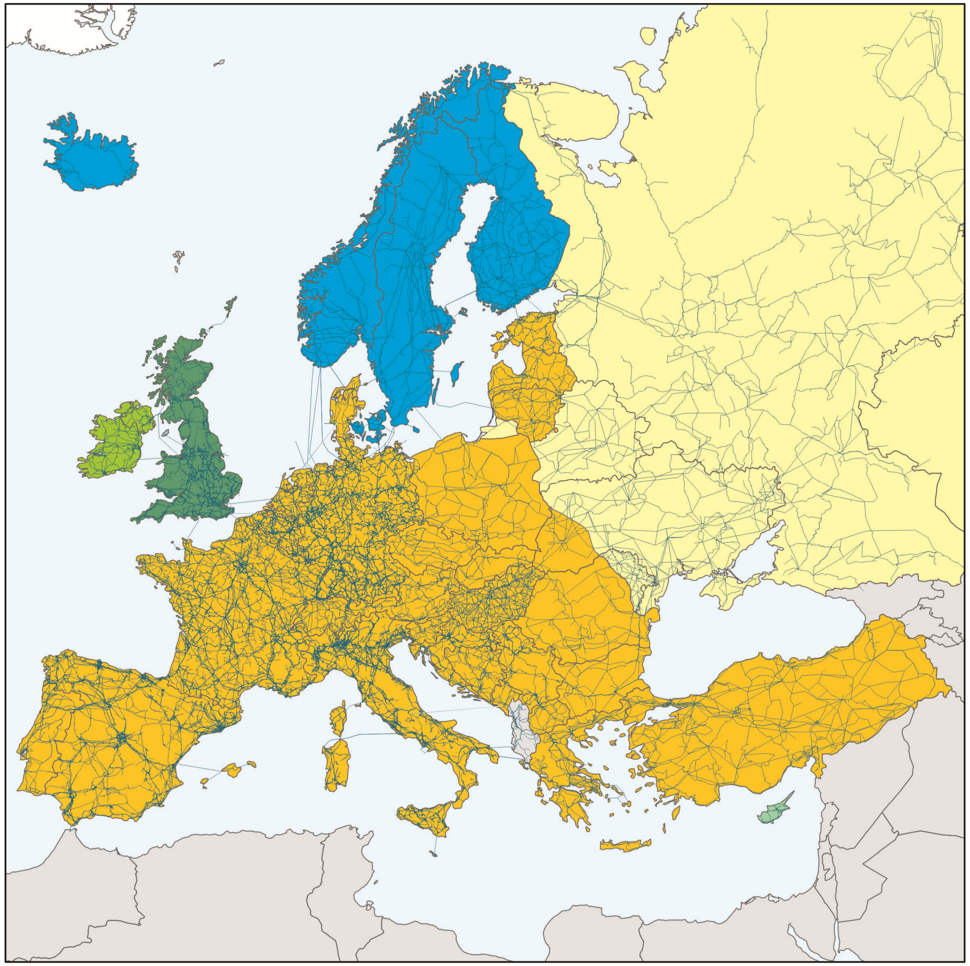
European transmission system (2020, planned)



Source: JRC

Pan-European study

European transmission system (2030, preliminary)



Source: JRC

Pan-European study

The Pan-European study, based on **EU30+ zonal model**, at 2020 and 2030 endogenously includes:

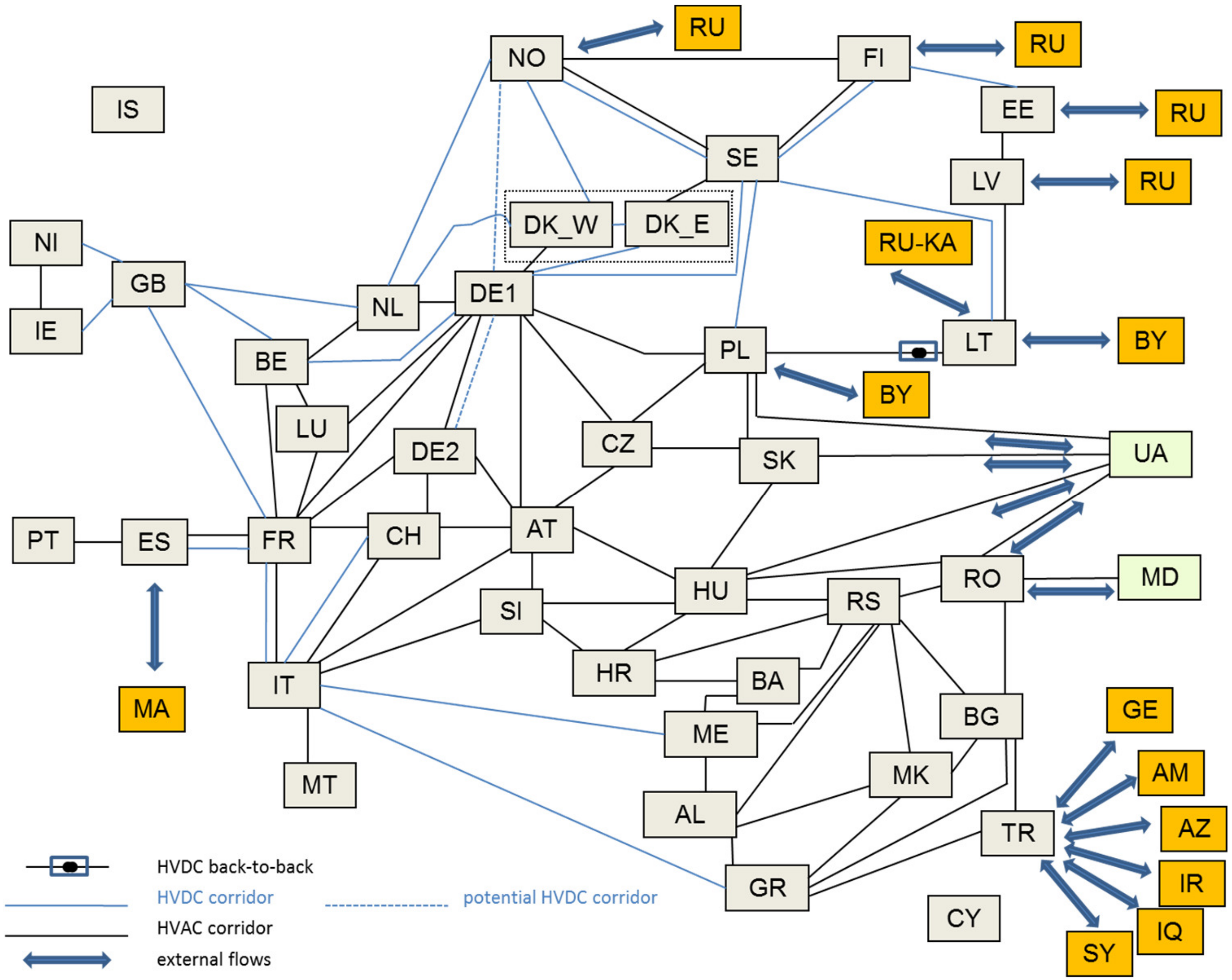
- EU28 countries -> 30 systems (including 2 German zones + Northern Ireland)
- EEA countries -> 3 systems
- Western Balkans -> 5 systems
- Turkey
- 2-3 offshore islands (only on/after 2030)?

Pan-European study at 2020 and 2030 exogenously includes:

- Bordering systems of North Africa
- Bordering systems of Middle East
- Bordering systems of eastern edge (Russia, Belarus, Ukraine, Moldova)

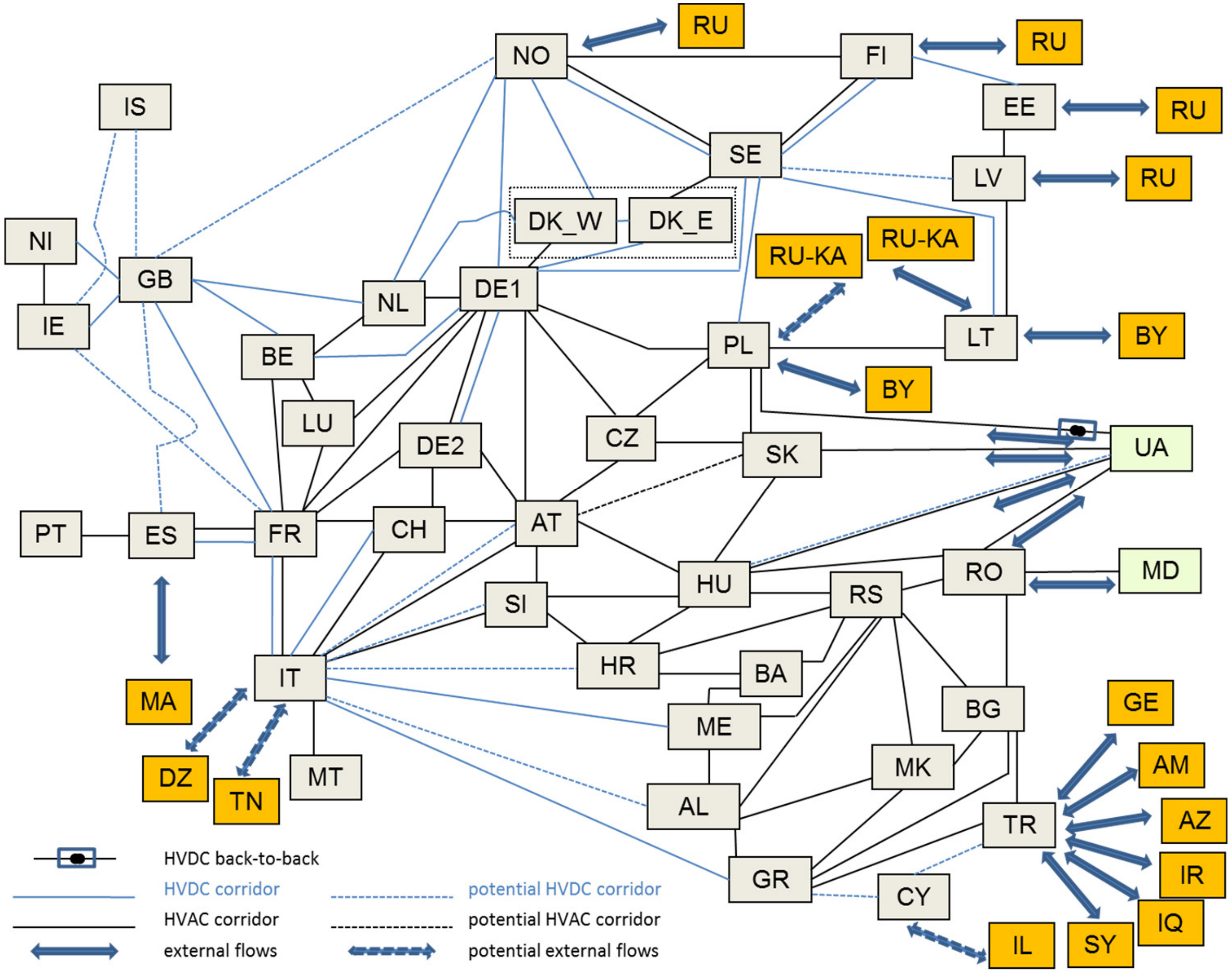
Pan-European study

Pan-European zonal model (2020, planned)



Pan-European study

Pan-European zonal model (2030, potential/updated)



Pan-European model: inputs

Data requirements:

- Generation
- Demand
- Profiles
- NTC
- PTDF
- Costs

The data collection, started from the 7 study countries of the regional cases, has taken longer than expected due to different constraints and issues: this has been also due to the need for strict correlation and coordination between pan-European and regional studies, in order to ensure proper data input-output consistency and transfer.

Pan-European model: inputs

Data requirements and main sources for the Pan-European study:

Generation

- Installed capacities for each technology type/category (ENTSO-E, TSOs, NRAs, WP5 partners, RSE, EEG)
- Thermal plants availability, efficiency, maintenance (SUSPLAN, TSOs, WP5 partners)
- Hydro plants characteristics, reservoir and pumping volumes, inflows, operation hours (TradeWind, Eurelectric, ENTSO-E, TSOs, WP5 partners, NREAPs, RSE)
- Solar timeseries (JRC)
- Wind timeseries (SUSPLAN/TradeWind, TSOs, RSE)
- CSP timeseries (UPComillas)
- Wave, tidal and DWW timeseries (EirGrid)
- CHP timeseries (WP5 partners, TSOs)
- Biomass and geothermal operation hours (NREAPs, TSOs, WP5 partners, EEG)
- Fuel costs (ENTSO-E)
- Emission factors (TradeWind)
- CO2 penalty tax (EC Trends to 2050, EU, IEA WEO)

Pan-European model: inputs

Data requirements and main sources for the Pan-European study:

Demand

- Total consumption level (ENTSO-E, TSOs, WP5 partners, EEG)
- Load timeseries (RSE, ENTSO-E, TSOs, WP5 partners)

Transmission

- NTC values (ENTSO-E TYNDPs, RSE, TSOs, WP5 partners)
- PTDF matrix (RSE, ENTSO-E STUM2020)
- Exogenous regions injections (RSE, ENTSO-E, WP5 partners, TSOs)

Pan-European model: outputs

MTSIM **main outputs for techno-economic assessments**:

- Zonal generation dispatch
- Dispatch cost
- Inter-zonal flow transits
- Load shedding (EENS)
- RES curtailment (EIE)
- CO2 emissions
- Zonal costs/prices

Pan-European model: 2020 inputs

Total generation capacity at 2020:

• Nuclear	126.9	GW
• Lignite	65.6	GW
• Hard Coal	105.5	GW
• Gas (CCGT, OCGT, ST)	245.1	GW
• Oil/oil shale	23.8	GW
• Other non RES (CHP, waste)	54.5	GW
• Hydro (ROR, reservoir, PHES)	260.7	GW
• Wind (onshore, offshore)	259.2	GW
• Solar (PV, CSP)	121.4	GW
• Other RES (biomass, geothermal)	41.8	GW

Total load demand at 2020:
3984 TWh

Pan-European model: 2020 inputs

Fuel costs at 2020:

• Nuclear	0.377 €/GJ
• Lignite	0.44 €/GJ
• Hard Coal	2.8 €/GJ
• Gas	7.99 €/GJ
• Mixed oil/gas	16.73 €/GJ
• Light oil	16.73 €/GJ

CO_2 penalty tax at 2020:

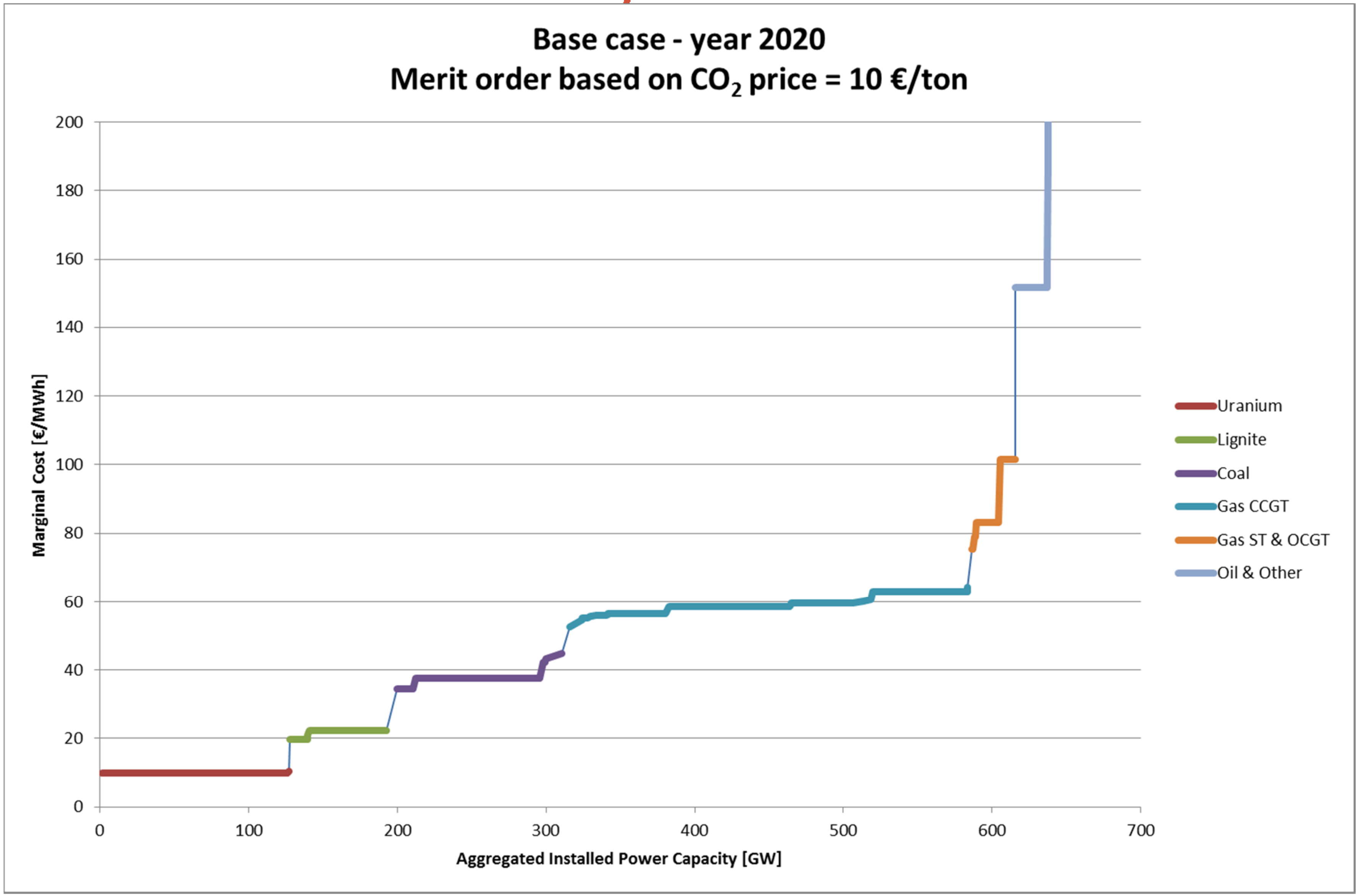
10 €/t CO_2 (base case)
16.5 €/t CO_2 (sensitivity analysis 1)
21 €/t CO_2 (sensitivity analysis 2)

Pan-European study results (2020)

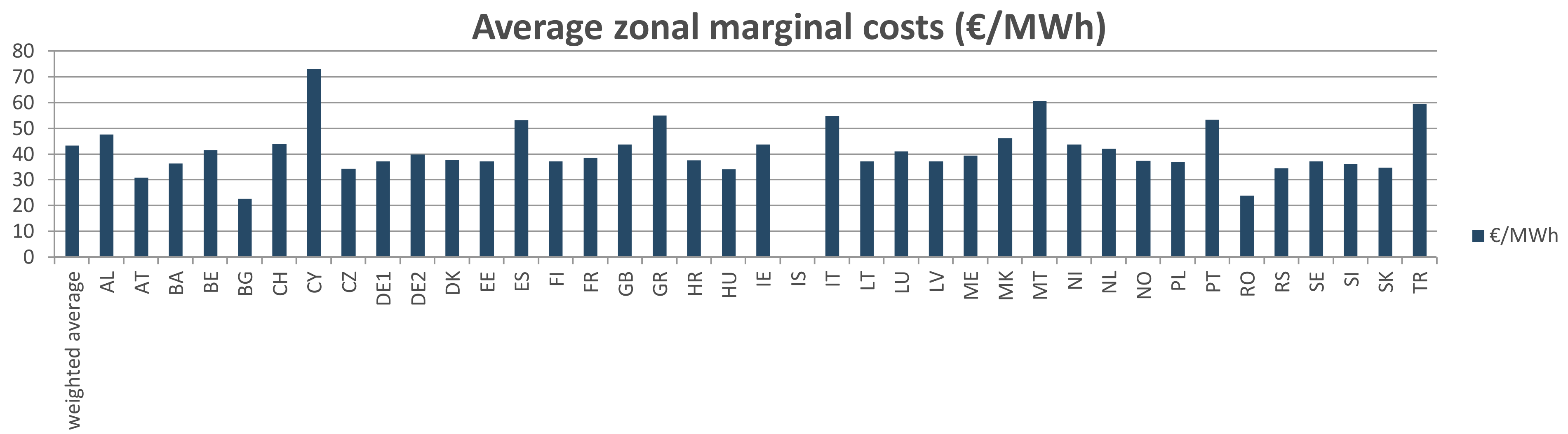
Main outcomes:

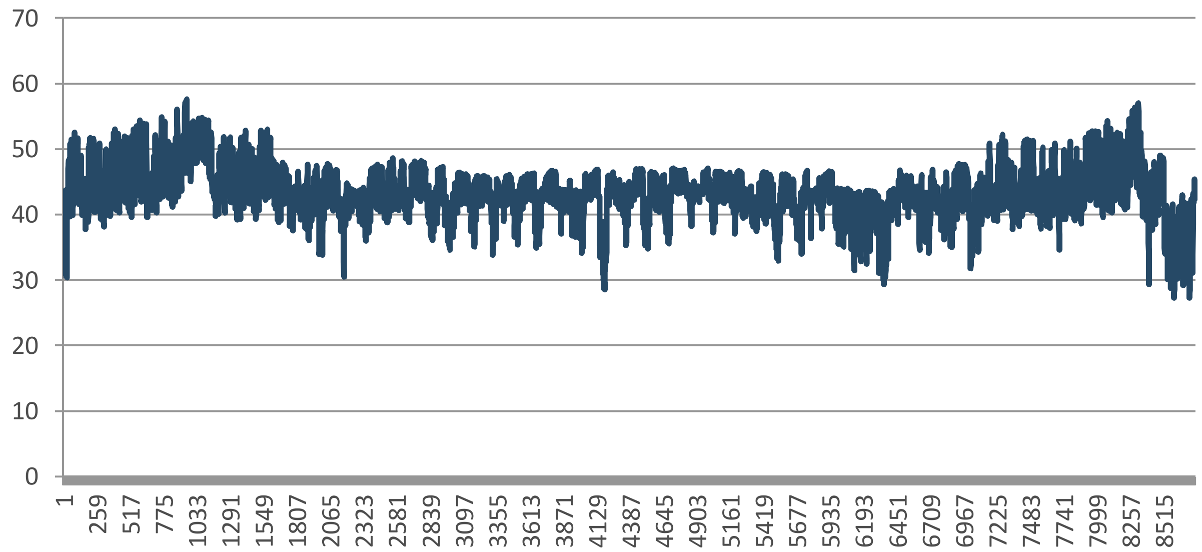
- Load shedding is null
- RES curtailment (2.67 TWh) is mostly concentrated in IE, IS and is very limited in DE1, ES, NI, PT
- Zonal costs are changing depending on countries, RES penetration, energy mix
- HVDC corridors are rather fully utilised

2020 base case inputs: merit order



2020 base case results: zonal costs



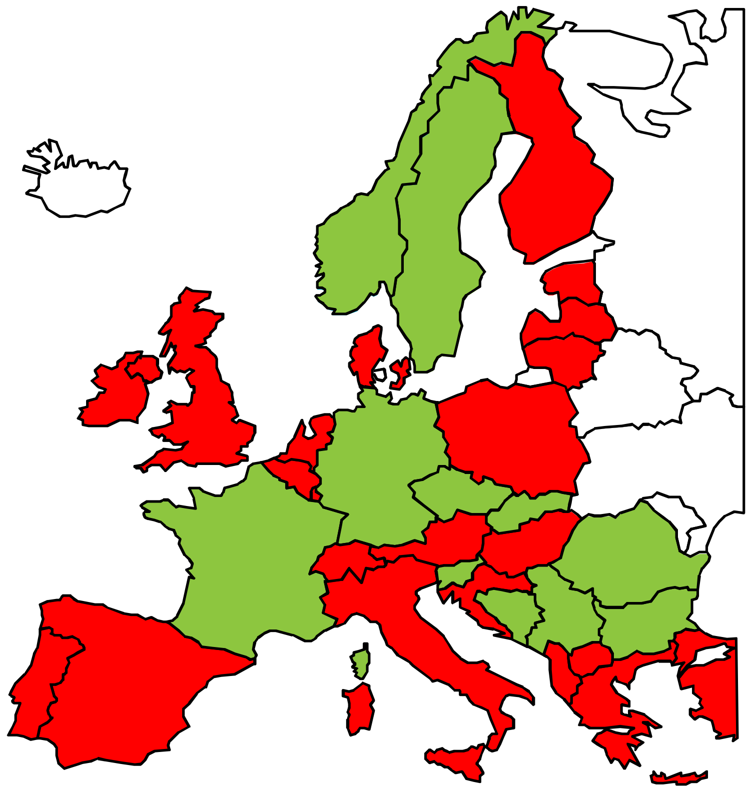


Average hourly zonal marginal cost (weighted over zonal load) in Europe (2020 base case) (in €/MWh)

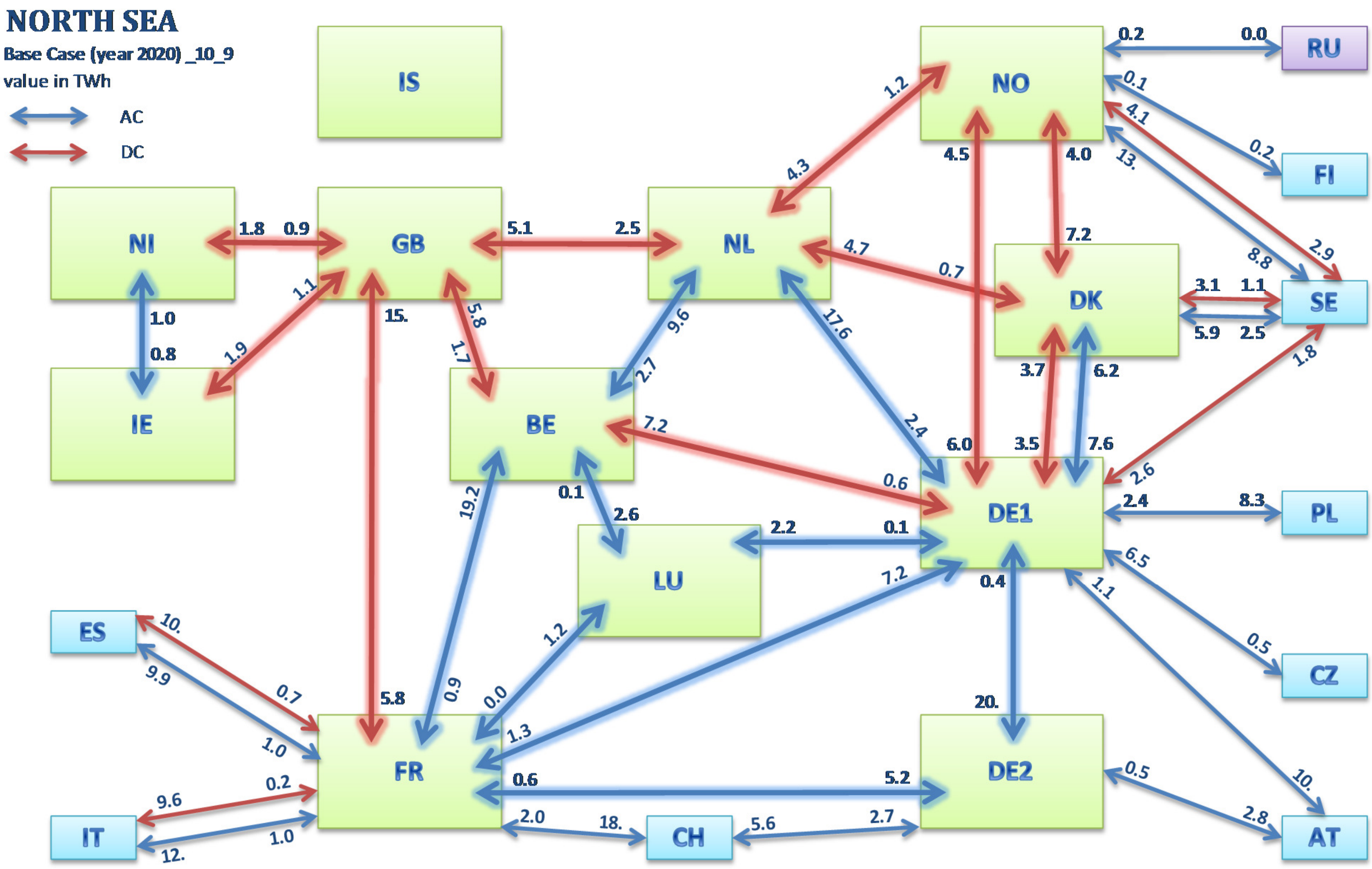
2020 base case results: inter-zonal flows

- The following countries/zones result to be net exporter at 2020:
BA, BG, CZ, DE1, FR, ME, NO, RO, RS, SE, SI, SK

- The following countries/zones result to be net importer at 2020:
AL, AT, BE, CH, DK, DE2, EE, ES, FI, GB, GR, HR, HU, IE, IT, LT, LU, LV, MK, MT, NI, NL, PL, PT, TR



2020 base case results: inter-zonal flows



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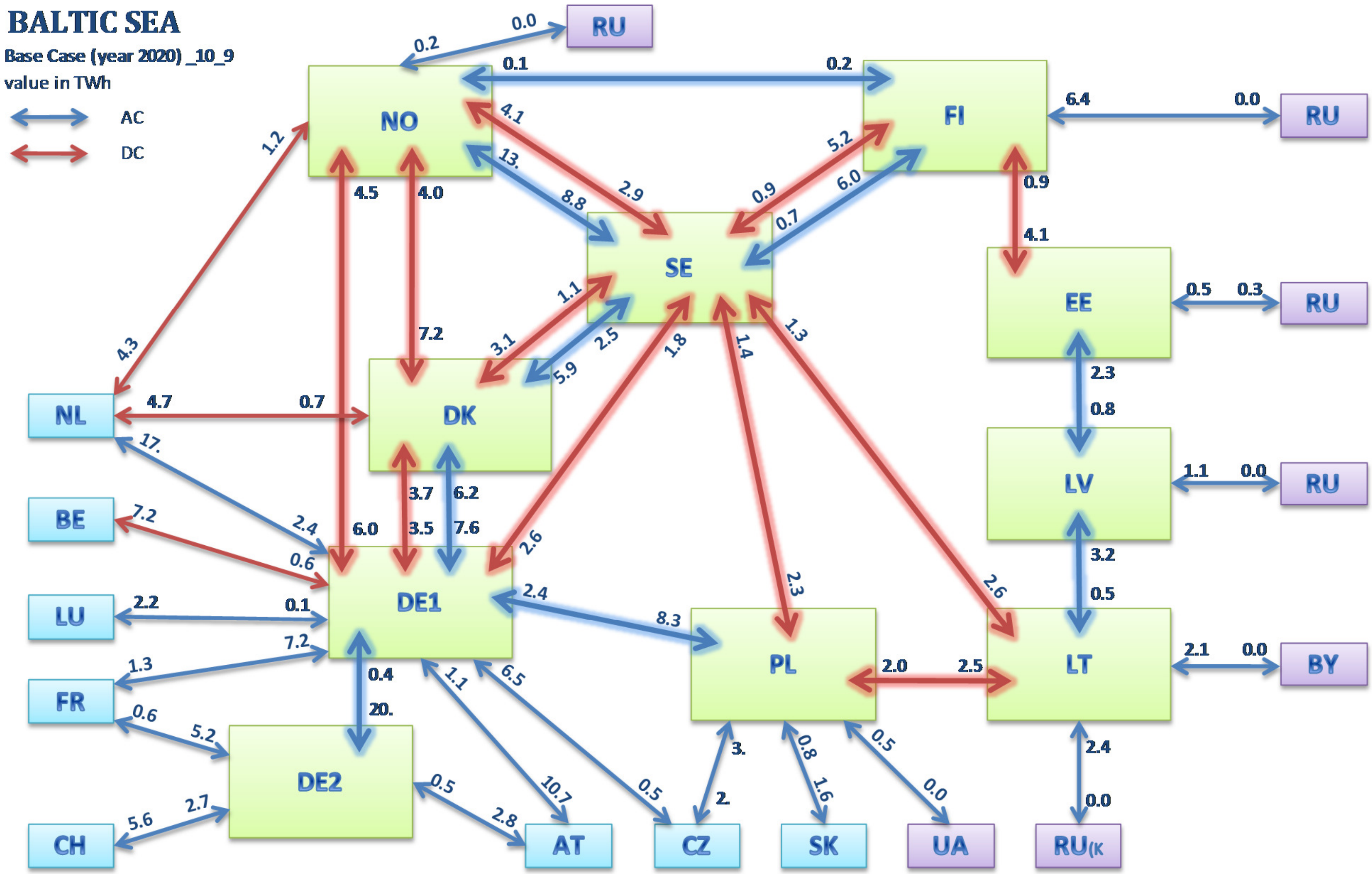

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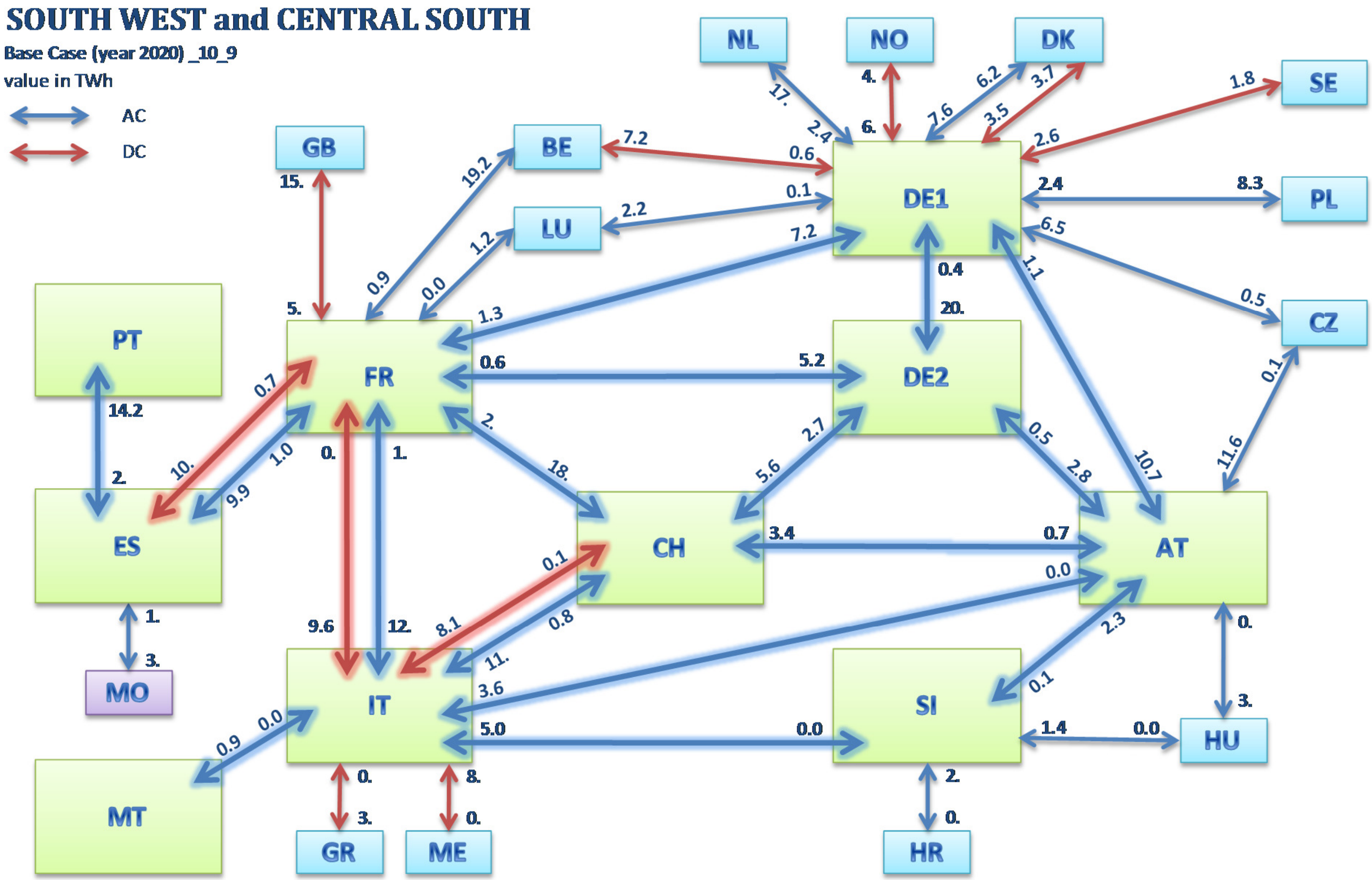

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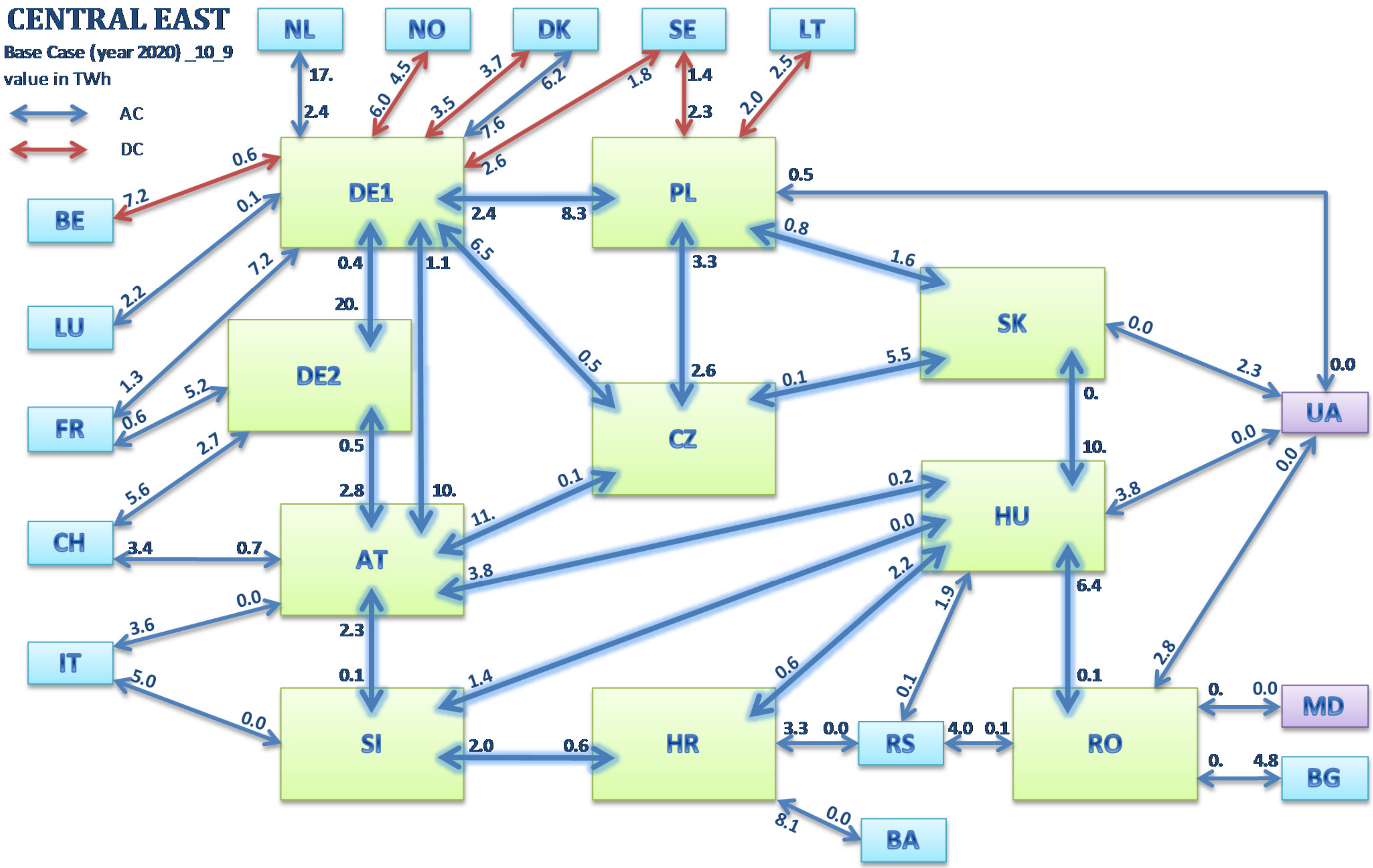
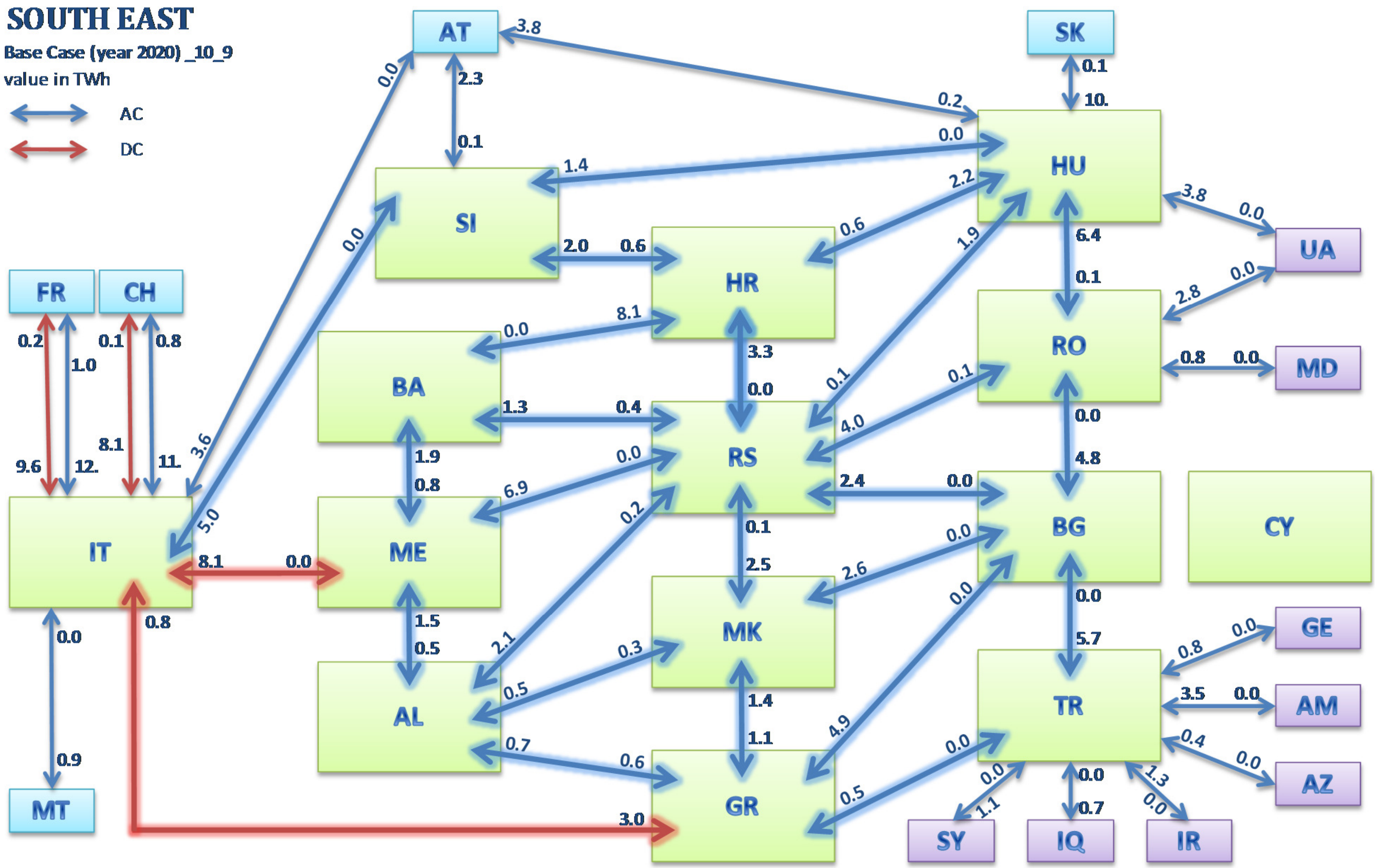
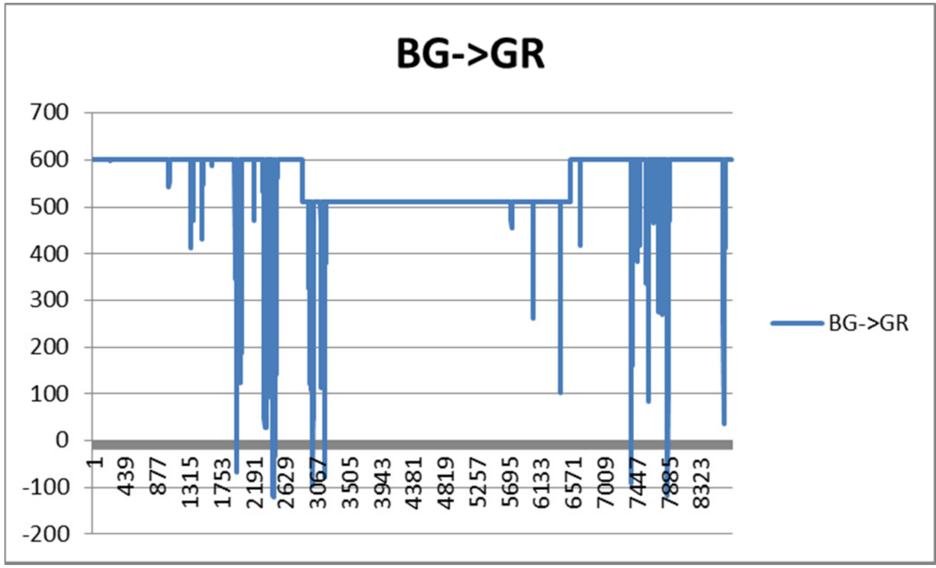
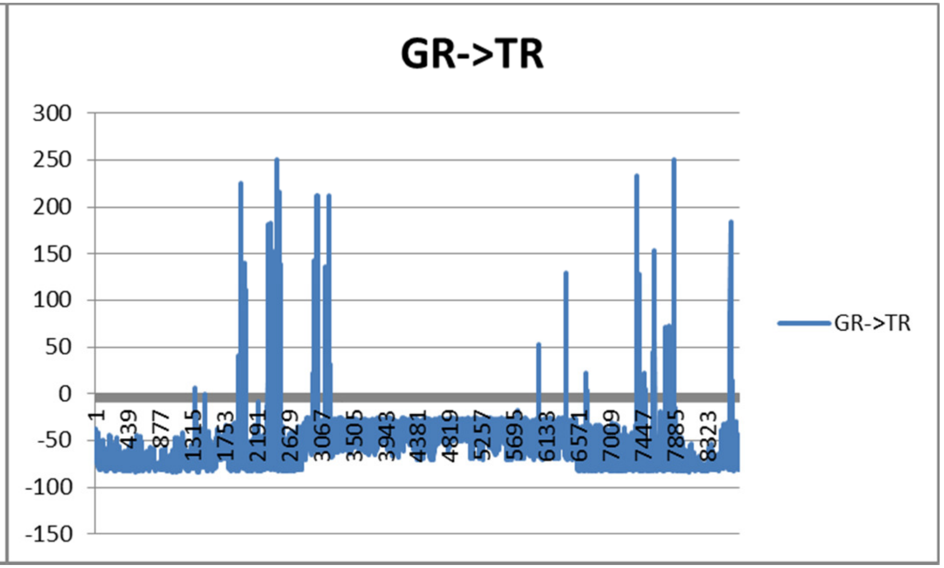


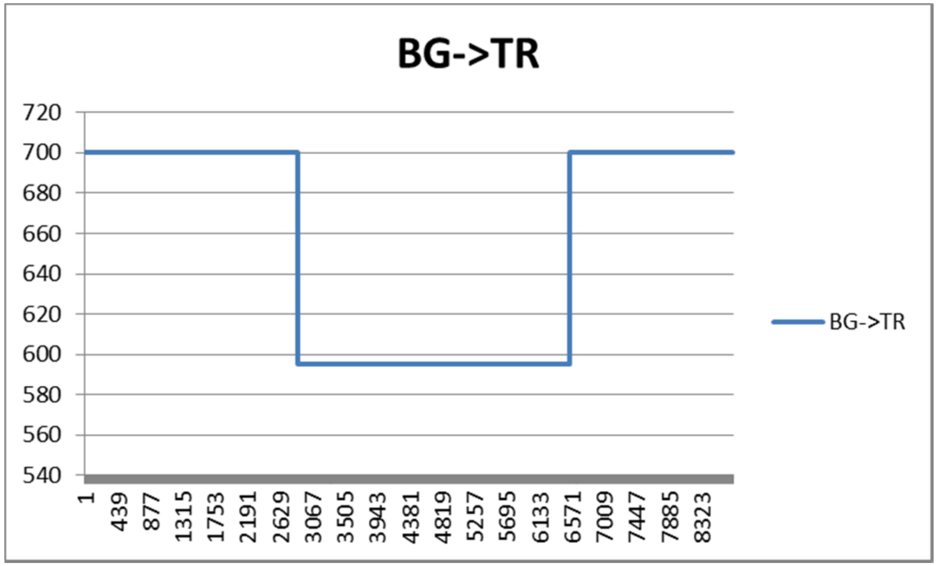
2020 base case results: inter-zonal flows



2020 base case results: inter-zonal flows







Elements for techno-economic assessments

- Costs
- Social Welfare
- CO_2 emission
- RES spillage
- Losses
- Reliability
- Resilience
- Flexibility
- Controllability
- Observability
- Socio-environmental impact

Elements for the discussion

- Long-term developments (beyond 2030)
- RES and demand growth in SEE region
- HVDC and other TGT developments in SEE region
- PHES and other EST developments in SEE region
- EVs and DSM/DR developments in SEE region

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IEE GridTech project

http://www.gridtech.eu

Thank you!